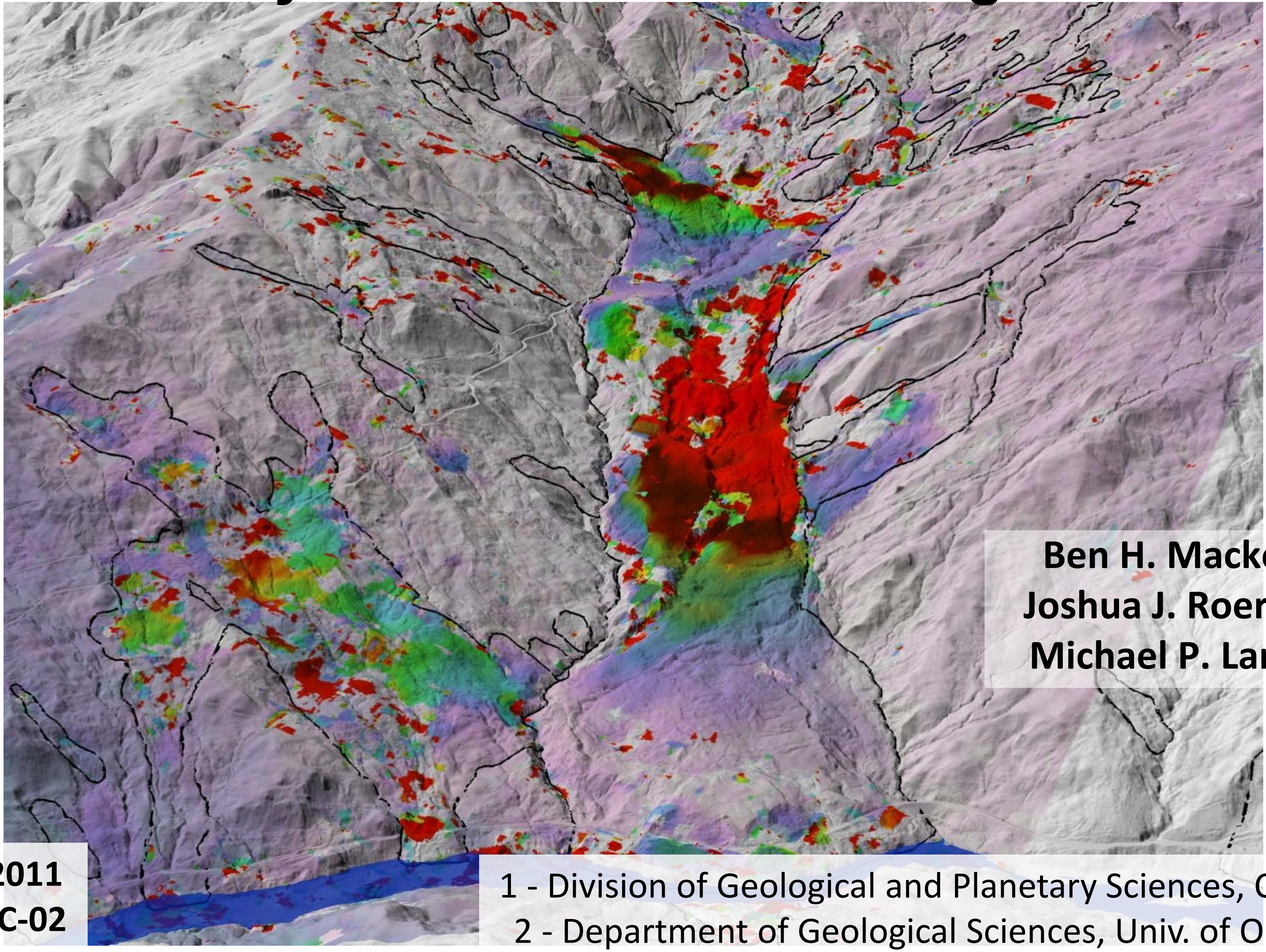
Automated optical image correlation to constrain dynamics of slow-moving landslides



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Outline

- Large slow-moving landslides
- Study Area - Eel River, northern California
- Challenges assessing long-term earthflow activity
- Previous manual mapping
- COSI-Corr applied to mapping landslide activity

Thanks to Sebastien Leprince and Francois Ayoub (Caltech / Imagin' Labs)

COSI-corr

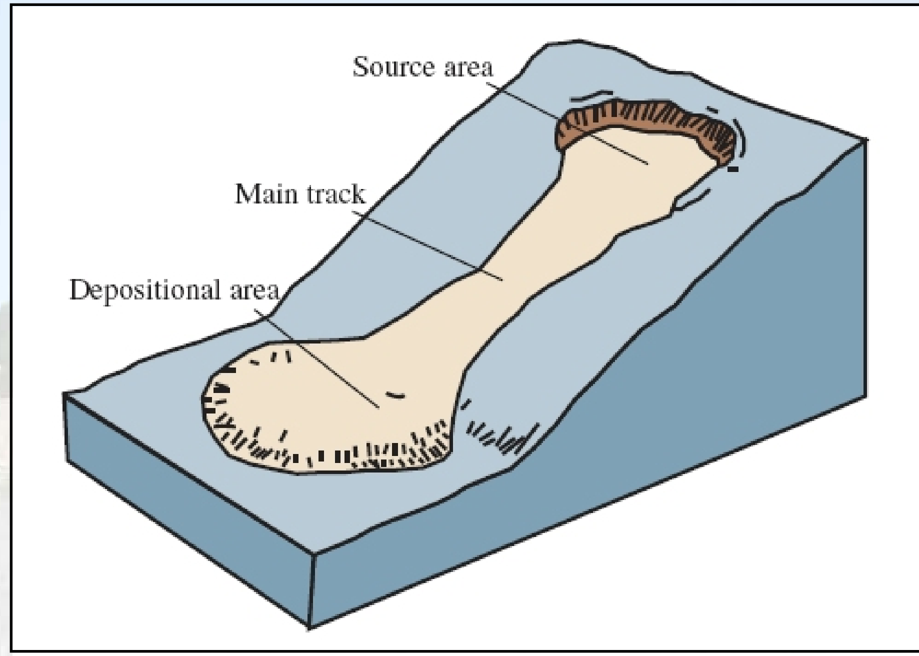
The National Center for Airborne Laser Mapping

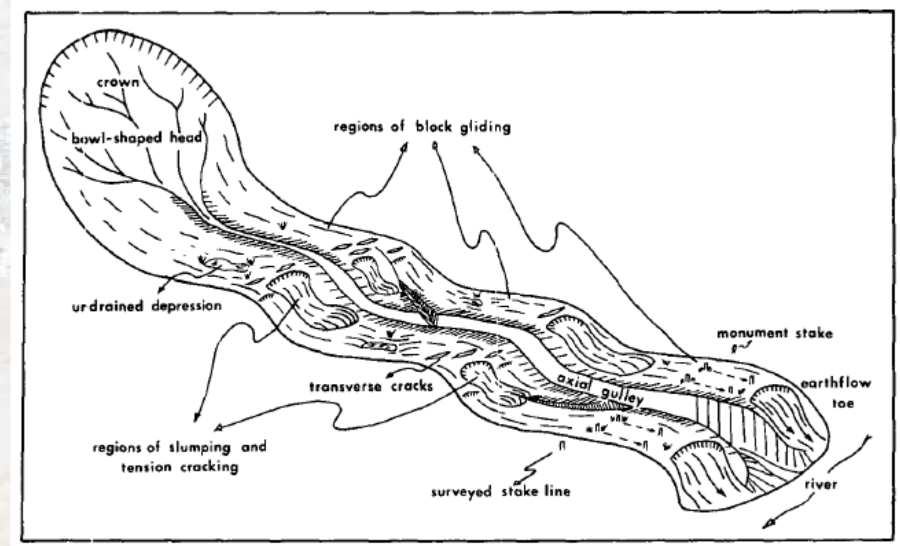
Keck Institute for Space Studies
California Institute of Technology
Jet Propulsion Laboratory

National Science Foundation
WHERE DISCOVERIES BEGIN
Geomorphology and Land Use Dynamics

Earthflows - large, slow-moving landslides

- Glacier-like ‘soil conveyors’
  - Up to 5 km long
- Predominantly Plug flow
  - Sliding along transient shear margins
  - Degree of internal deformation
- Fine grain sizes dominate mechanics
  - Clay rich
- Macro-scale flow-like morphology
- Deep-seated
  - >5 m deep
- Move ~1-2 m/a
  - Highly seasonal
  - Rainfall dependent
- Classical hourglass planform
  - Source amphitheater
  - Transport zone
  - Bulbous toe
- Seldom fail catastrophically



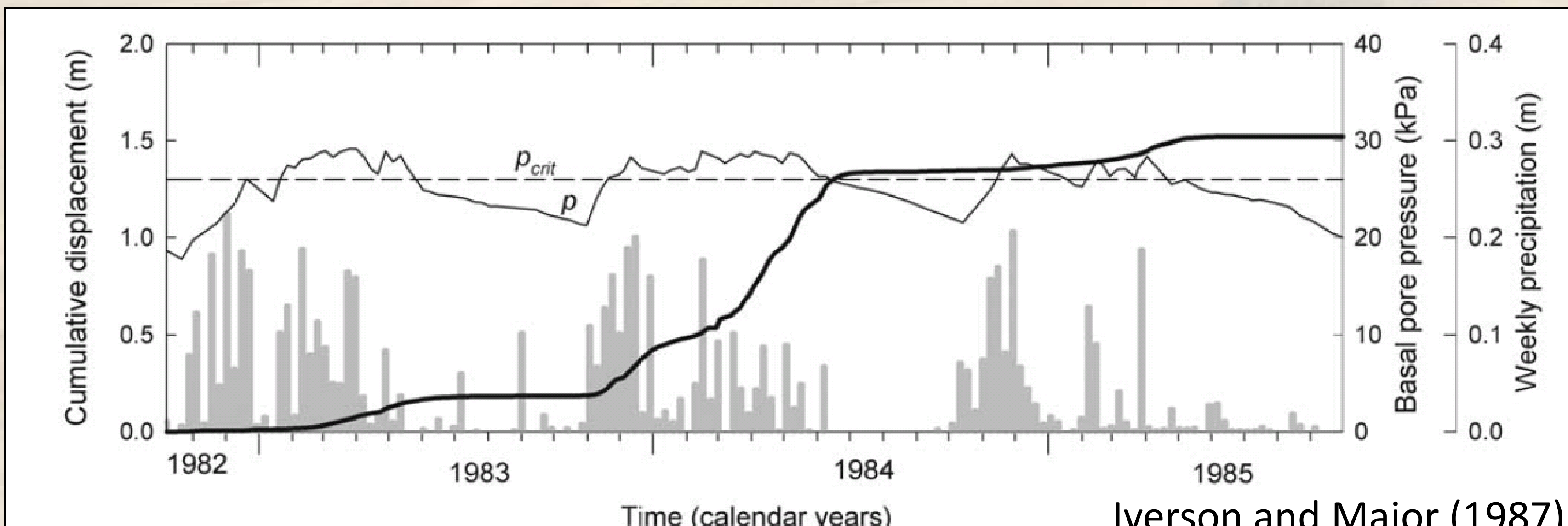


Kelsey (1978)

Slow moving landslides– What do we know?

- Much research on earthflow mechanics and seasonal movements
- Modern movement intensively monitored
  - InSAR, permanent GPS, continuous surveying, extensionometers, differential DEM's...
  - Recent technology – limited temporal coverage

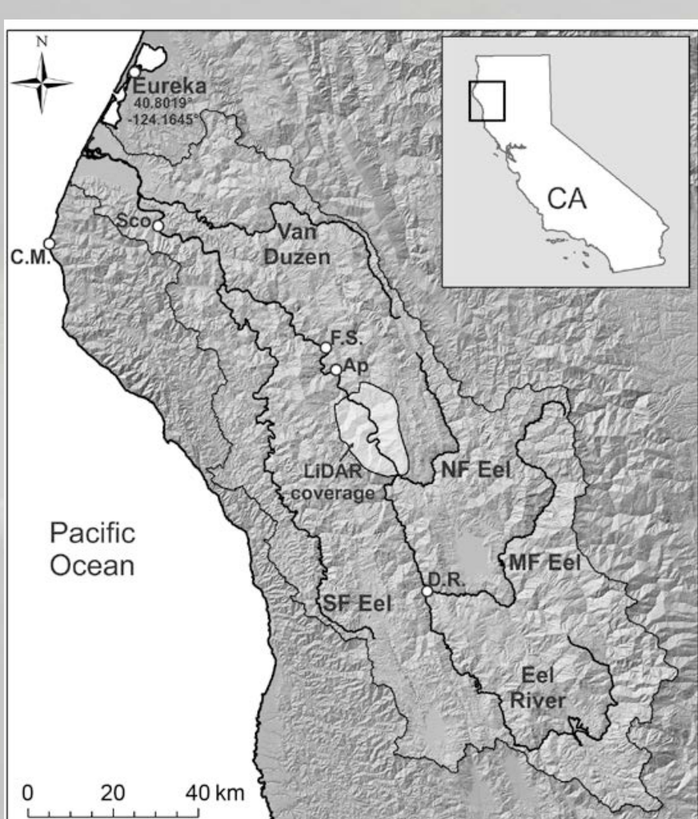
- Key questions
  - Decadal-scale behavior?
  - Duration of activity?
  - Channel incision vs topographic loading?
  - Correlation with longer-scale climate changes?
- **Requires spatially extensive record of deformation over long time periods**

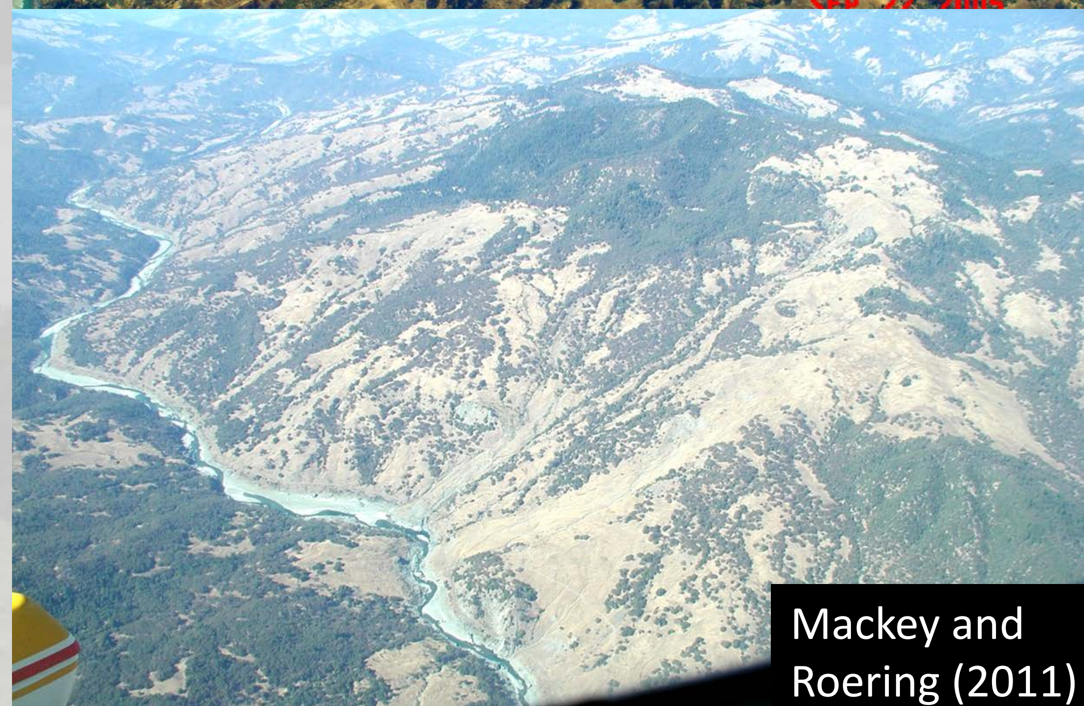


Iverson and Major (1987)

Eel River, northern California

- Mediterranean climate
  - 1.2 m/yr rain falling October-May
- Franciscan Complex mélange
  - Pervasively sheared argillaceous mélange matrix
  - Sandstone blocks
- 7% of landscape actively moving



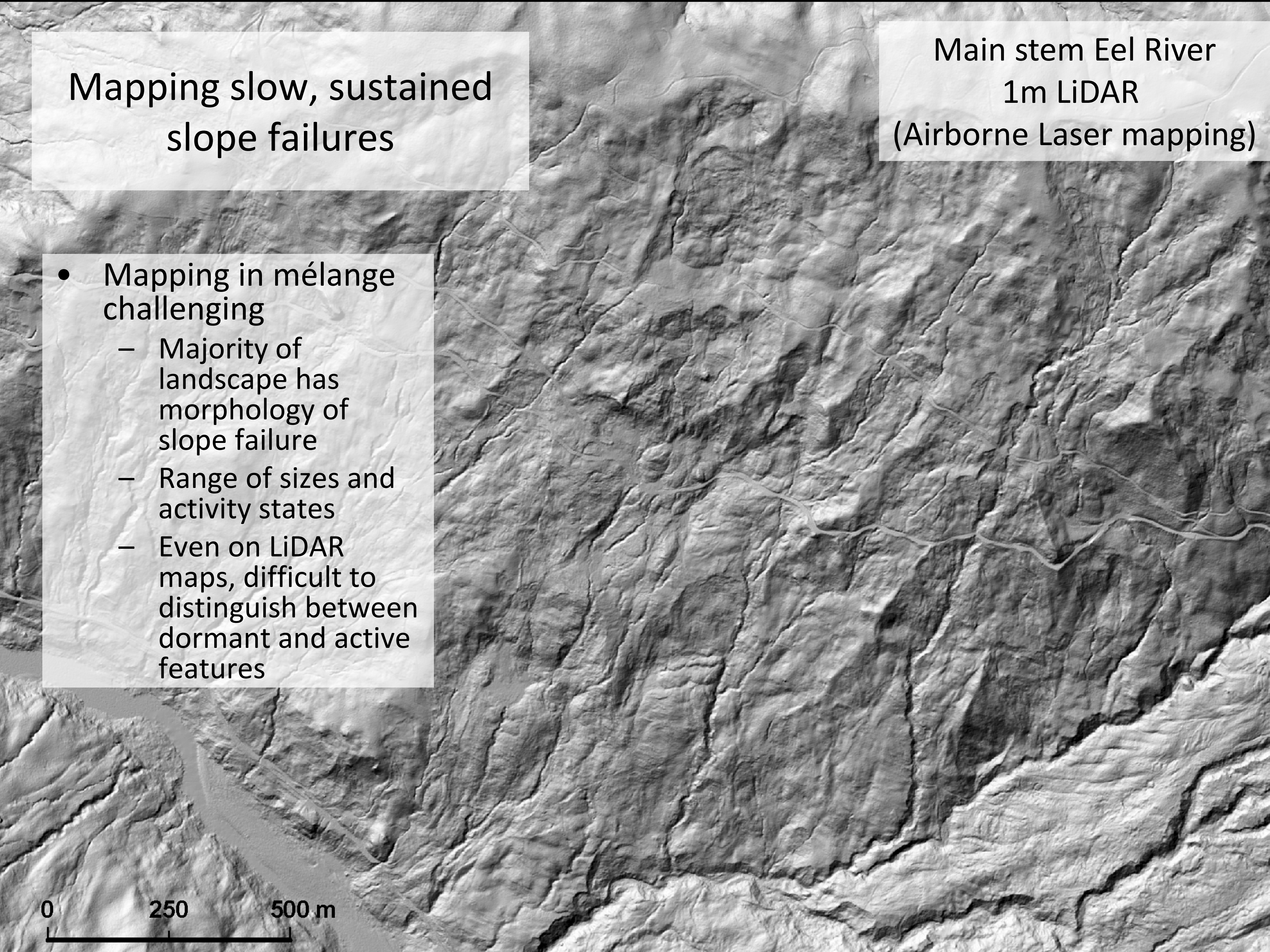


Mackey and Roering (2011)

Mapping slow, sustained slope failures

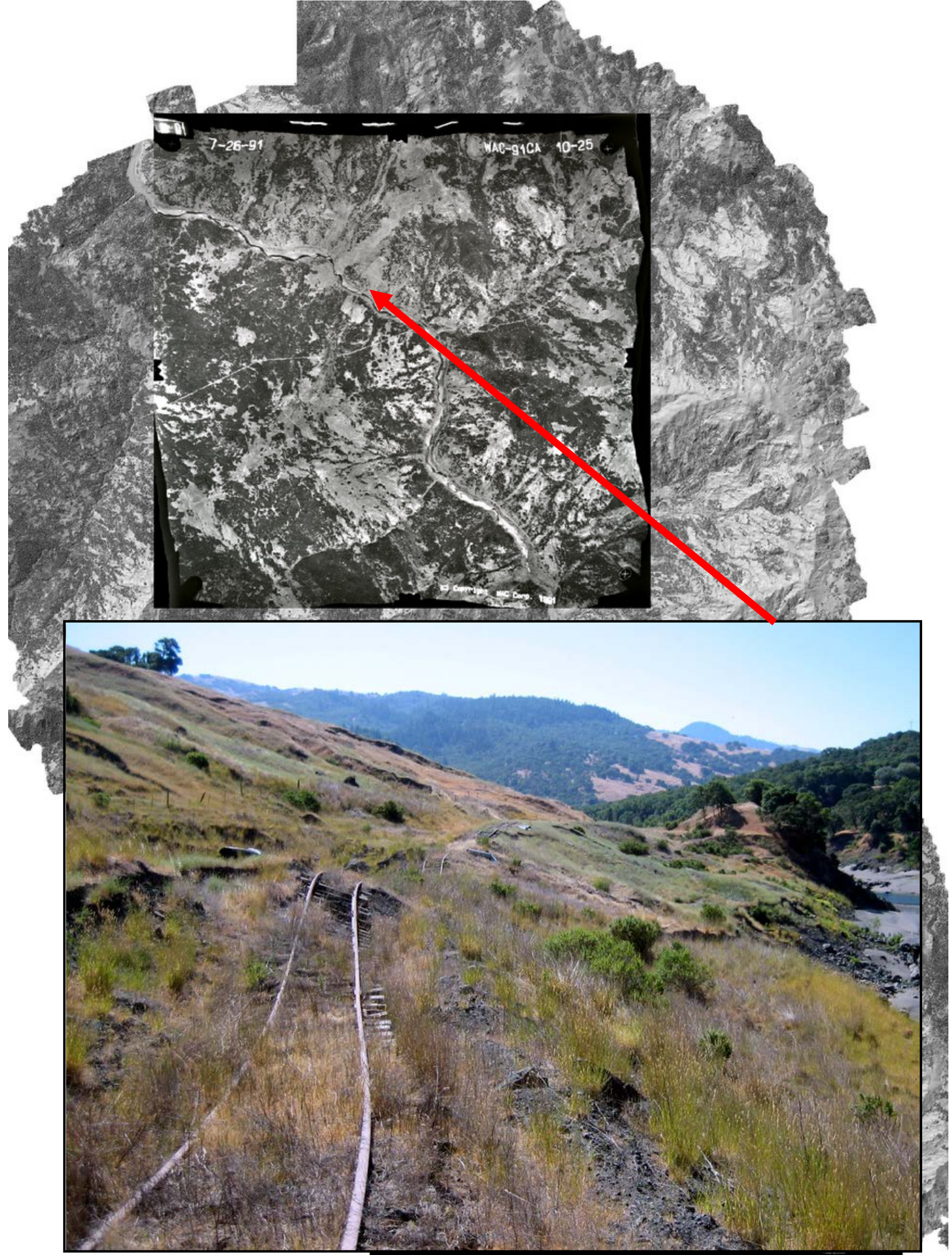
Main stem Eel River
1m LiDAR
(Airborne Laser mapping)

- Mapping in mélange challenging
  - Majority of landscape has morphology of slope failure
  - Range of sizes and activity states
  - Even on LiDAR maps, difficult to distinguish between dormant and active features



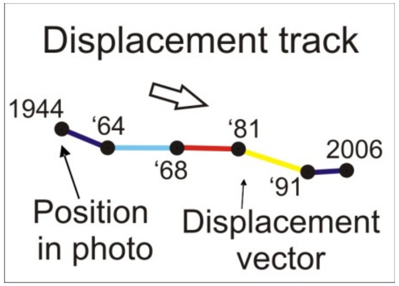
Orthorectification

- 230 km^2 LiDAR
  - DEM and derivative maps
  - 1 m resolution
- Historical aerial photos
  - High resolution scans (7-14 um)
  - Rectified using
    - LiDAR DEM for topographic model
    - Unfiltered LiDAR shaded relief as reference map
  - Camera information
    - Focal length
    - Fiducial coordinates
  - Co-locate stable ground control points on photos and LiDAR

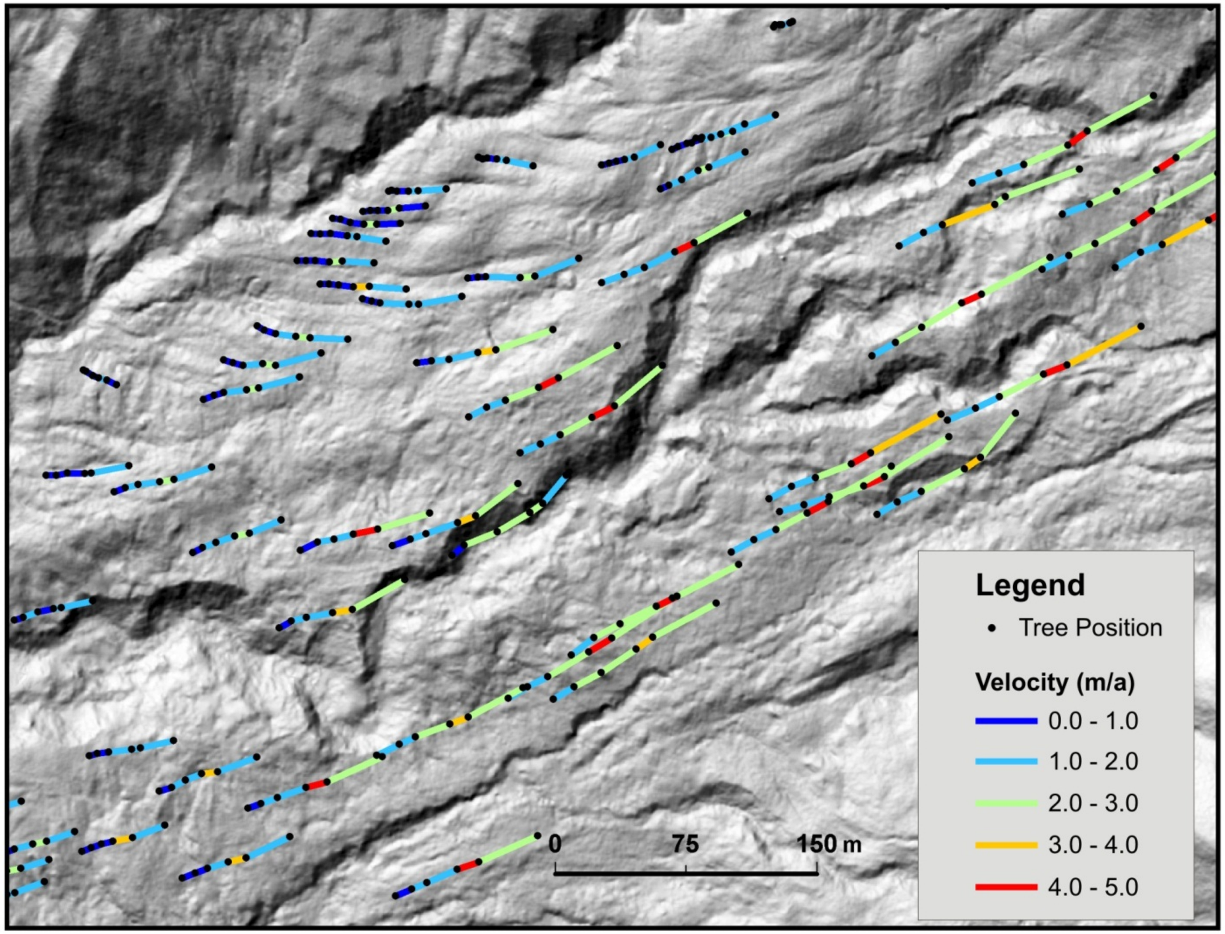


Boulder Creek Earthflow

Manual tree tracking



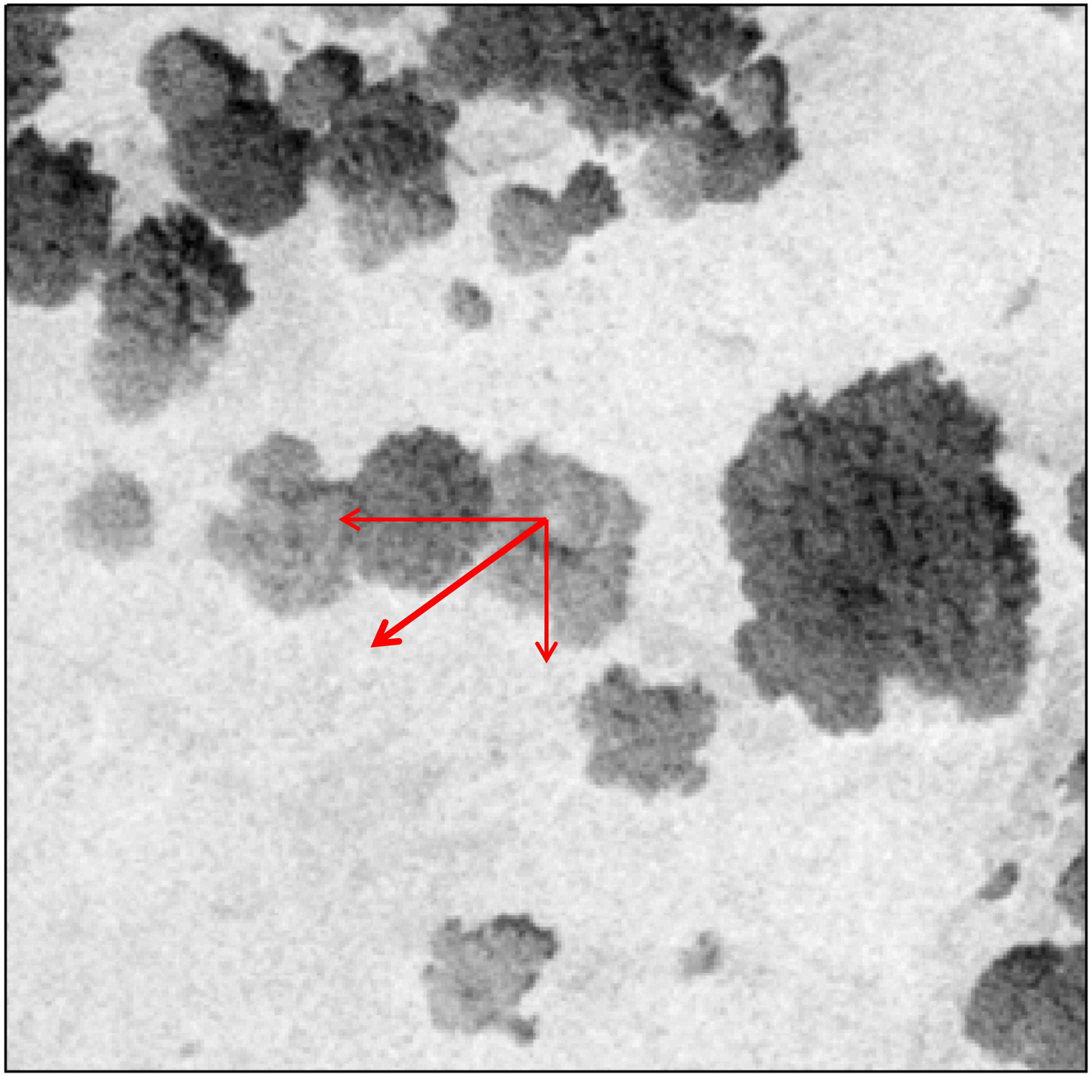
- Previous work focused on manually tracking the position of trees growing on the earthflow surface (Mackey et al. 2009)
- Generates vector field of movement
  - Where trees are present
  - Good data but spatially limited
- Laborious process
- Have to check whole study site for zones of possible movement



Boulder Creek Earthflow
Max ~175 m displacement

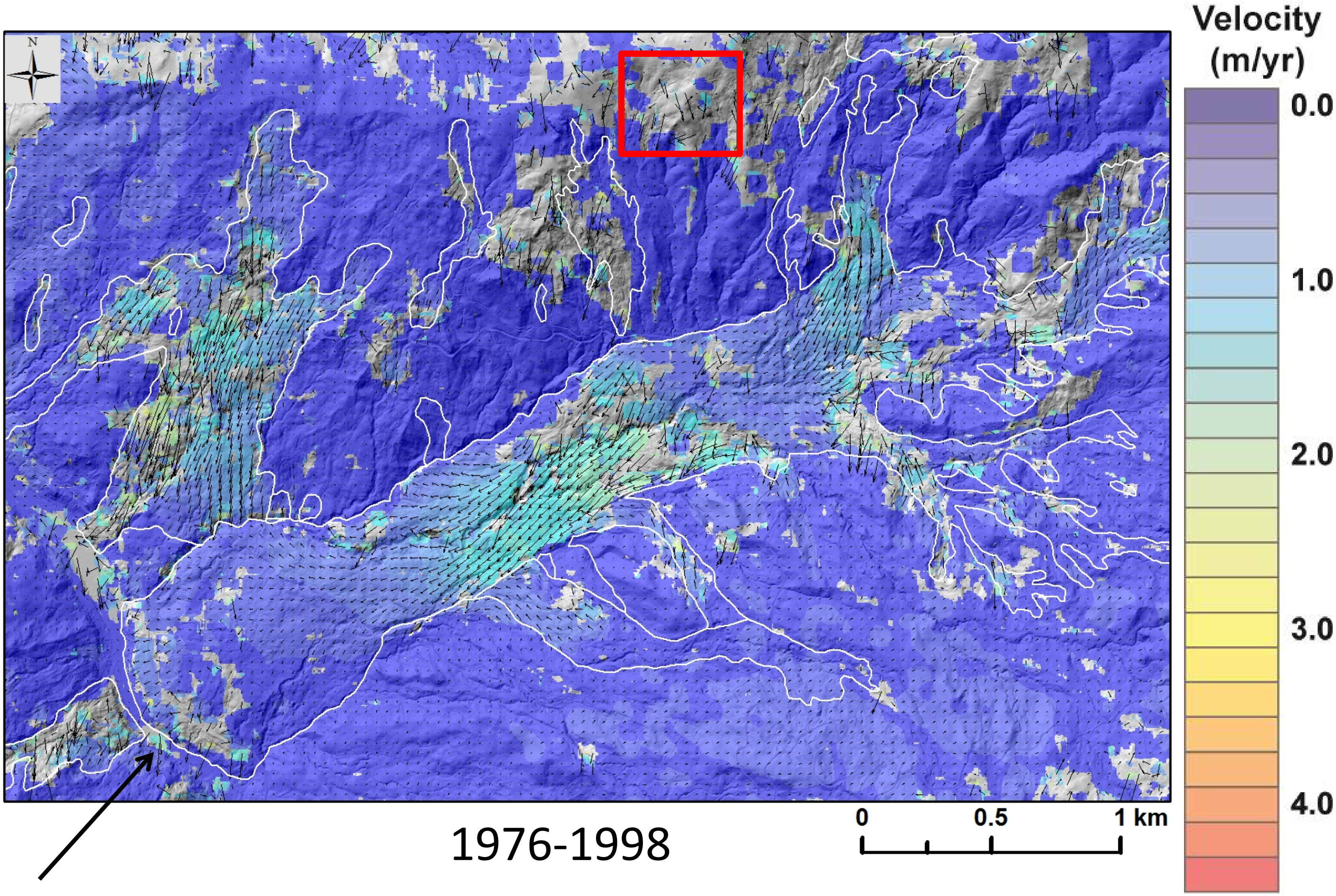
Automated change detection - COSI-Corr

- Sub-pixel correlation between sequential orthorectified images
- Moving window statistically compares sequential images for offset
  - Generates E-W and N-S components of motion
  - Filter low signal:noise ratios or unreasonable values
- Enables construction of detailed displacement fields
- Compare against manual mapping dataset



http://www.tectonics.caltech.edu/slip_history/spot_coseis/index.html

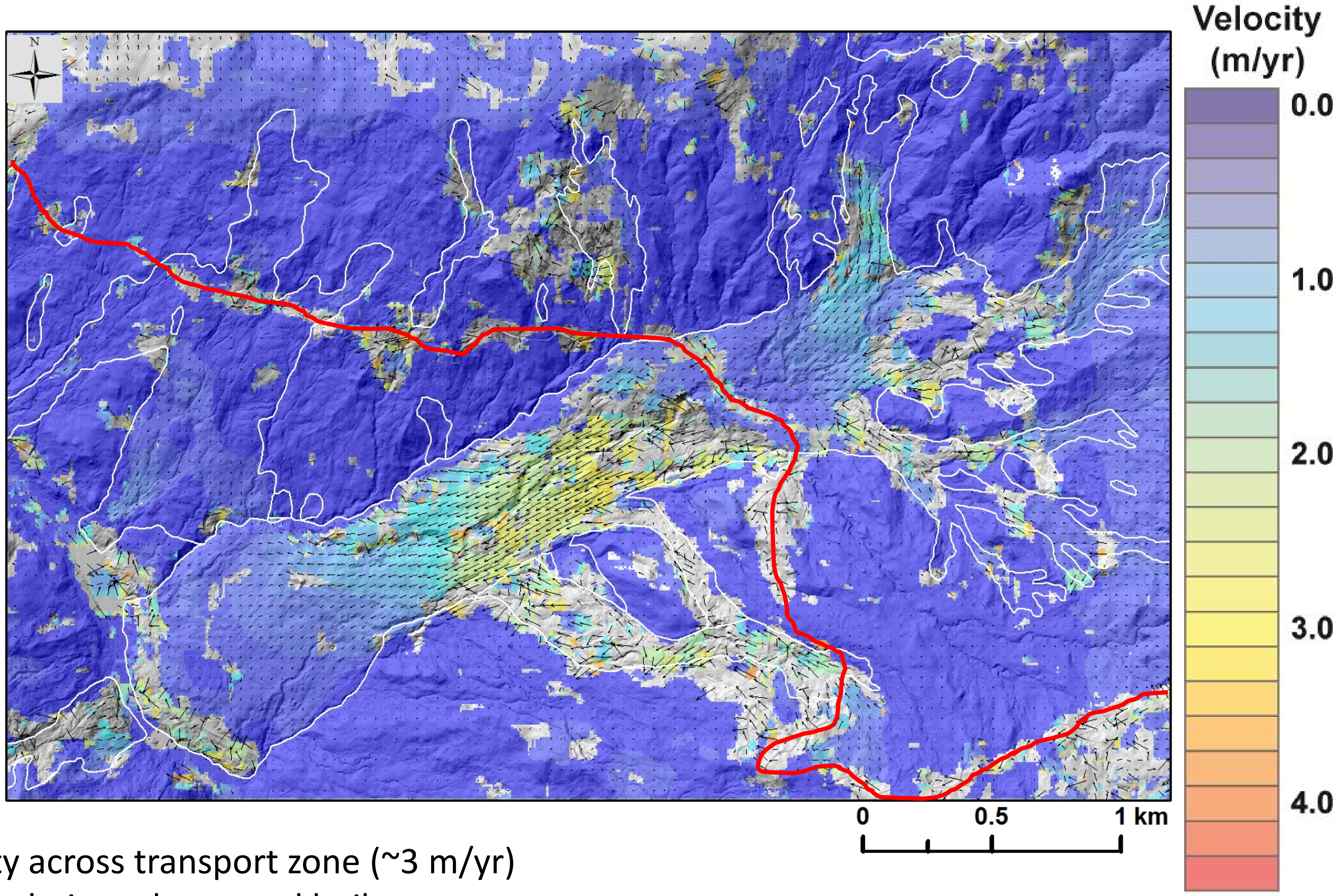
Decorrelation in grassy – highly disturbed areas



1976-1998

Active mapped flows 1944-2006
(Mackey and Roering, 2011)

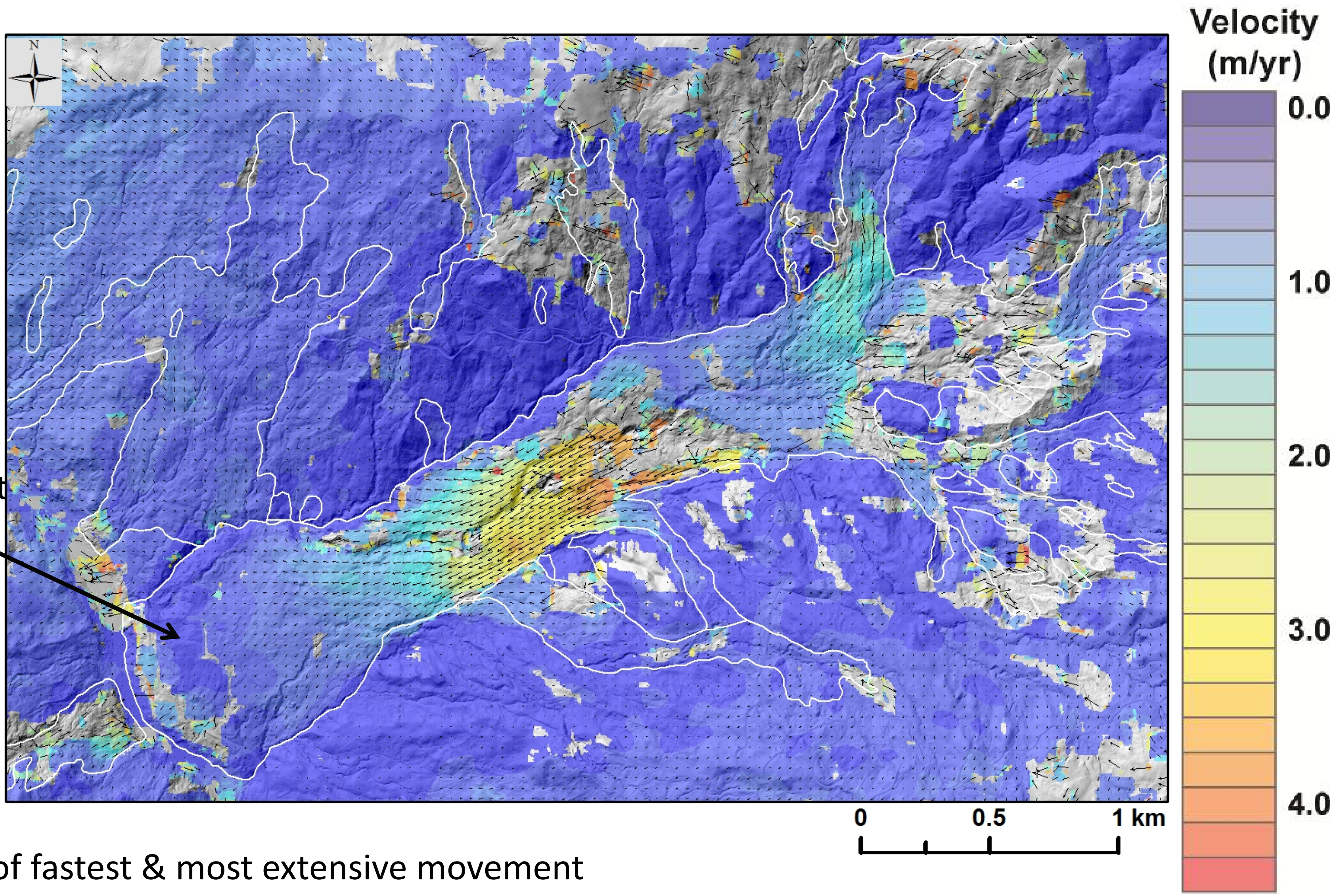
1944-1964



Activity across transport zone (~3 m/yr)
Decorrelation where road built

1964-1976

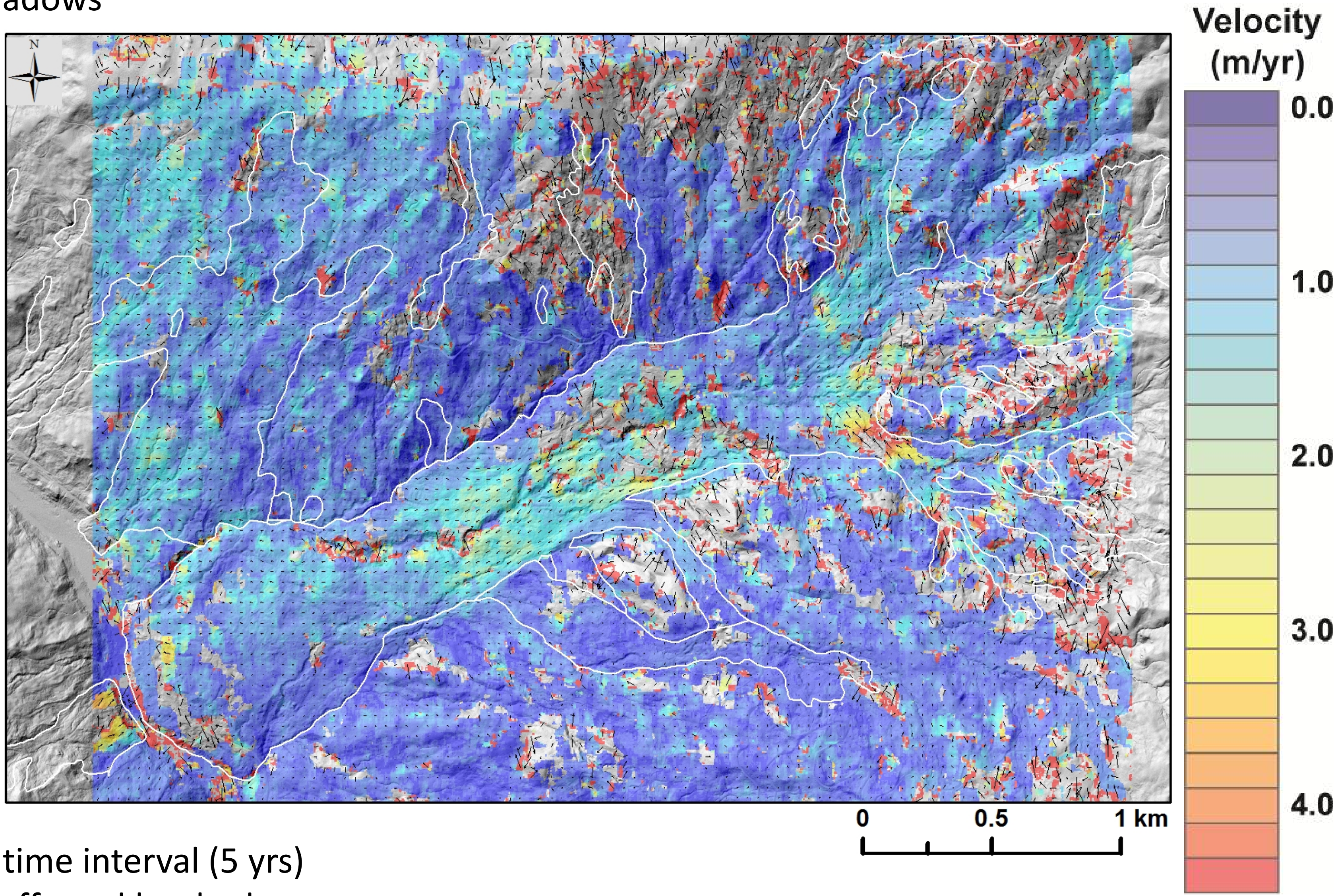
Minimal movement on toe



Period of fastest & most extensive movement
(Up to 5 m/yr in transport zone)
Decorrelates in zone of rapid movement (too much change)

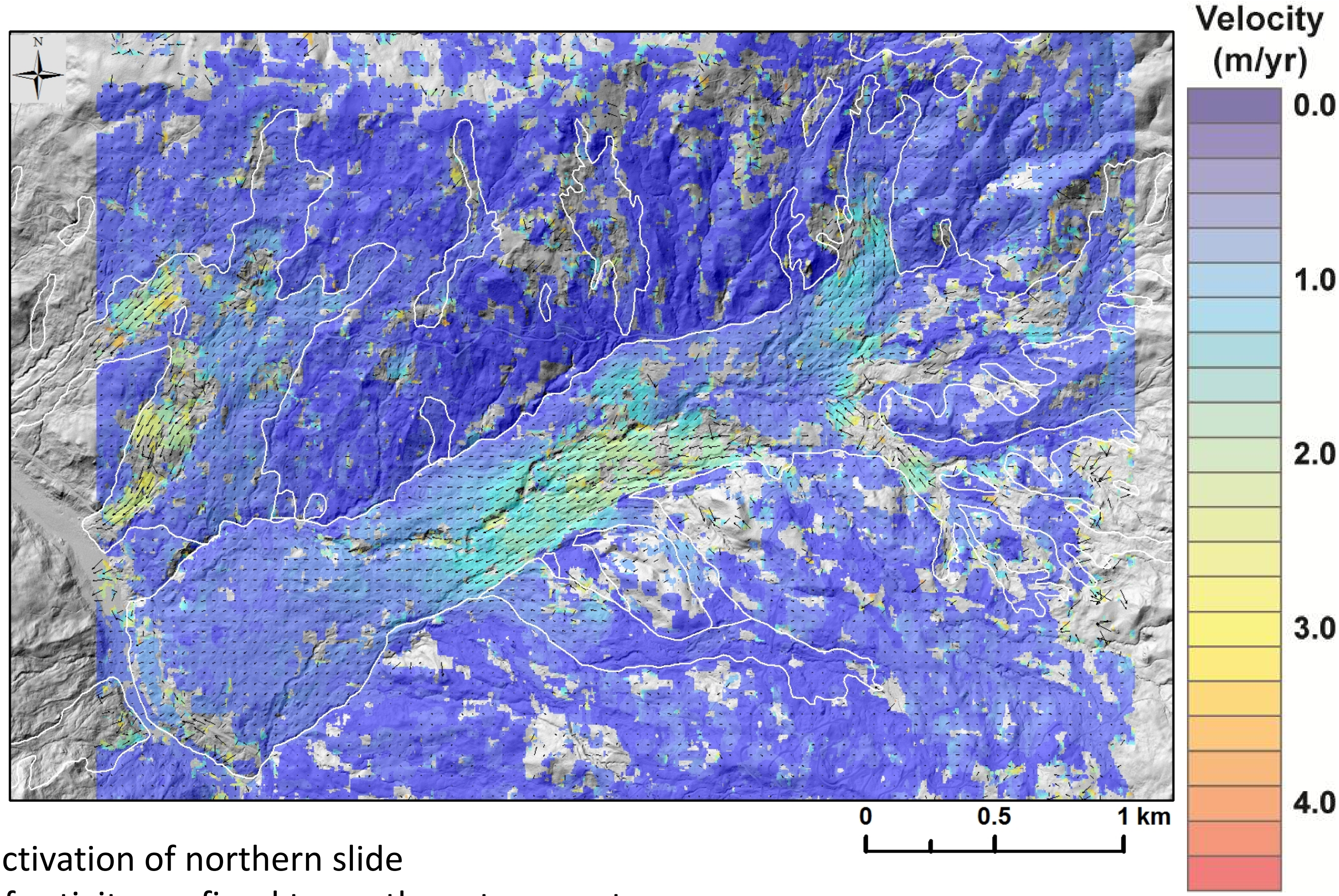
1976-1981

‘Patchiness’
from shadows



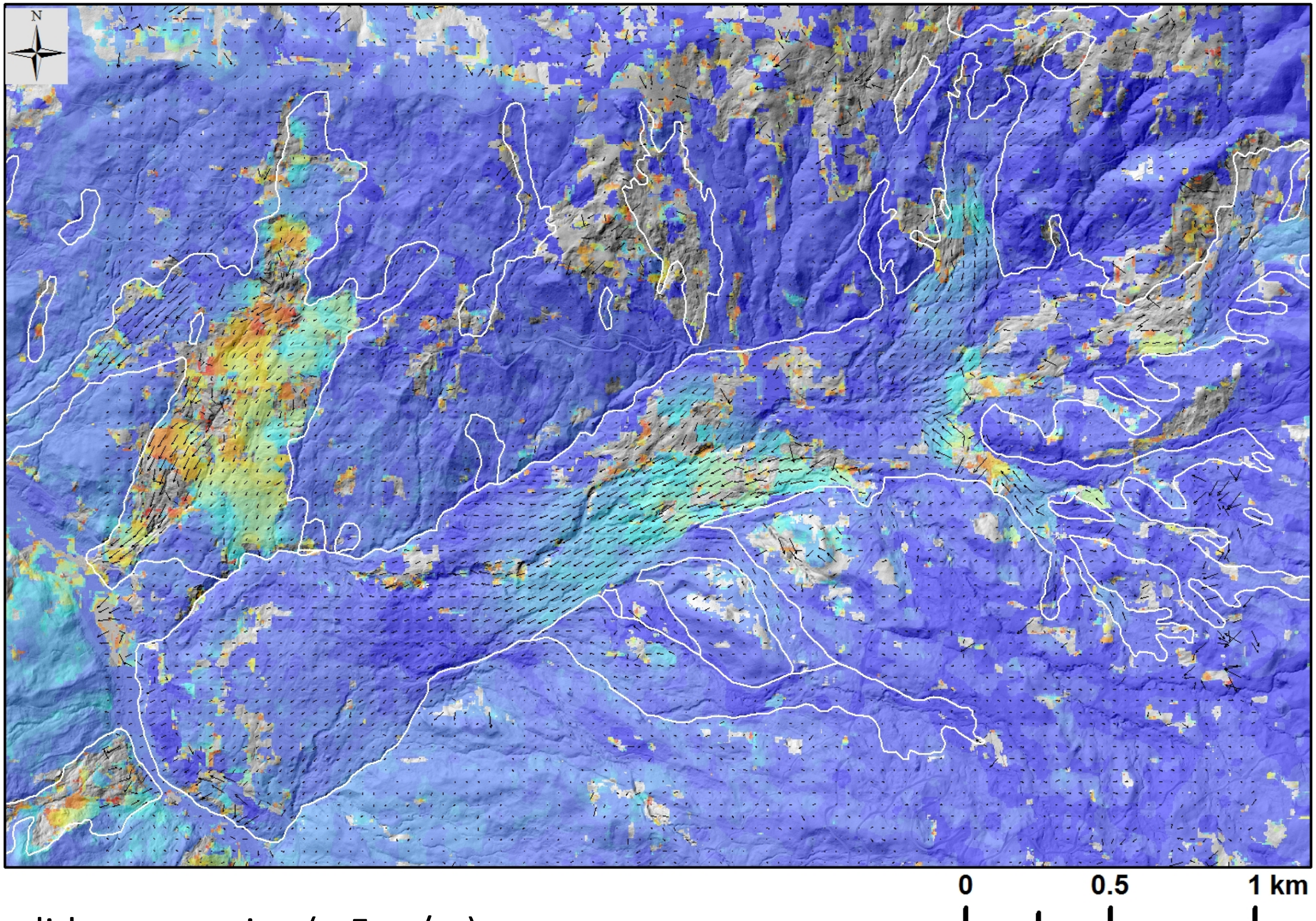
Shorter time interval (5 yrs)
Heavily affected by shadows
Flow slowing down (~2 m/yr)

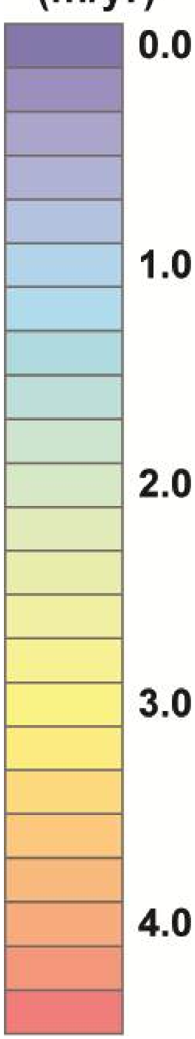
1981-1991



Partial activation of northern slide
Extent of activity confined to southern transport zone
Little movement on southern tributary flows

1991-1998

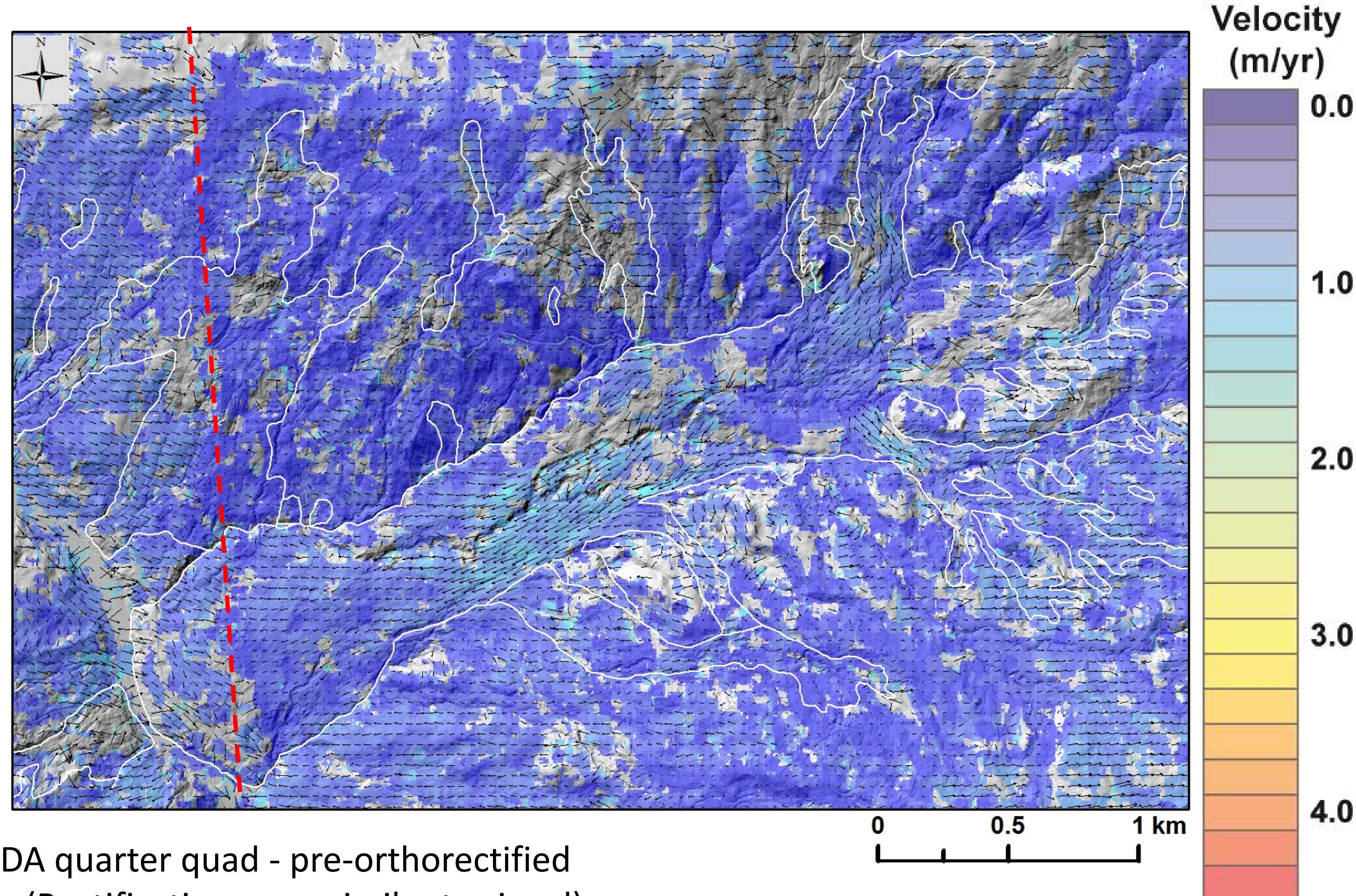




Northern slide very active (> 5 m/yr)
Low flow rates on main slide (~1 m/yr)
Upslope tributary nearly stopped

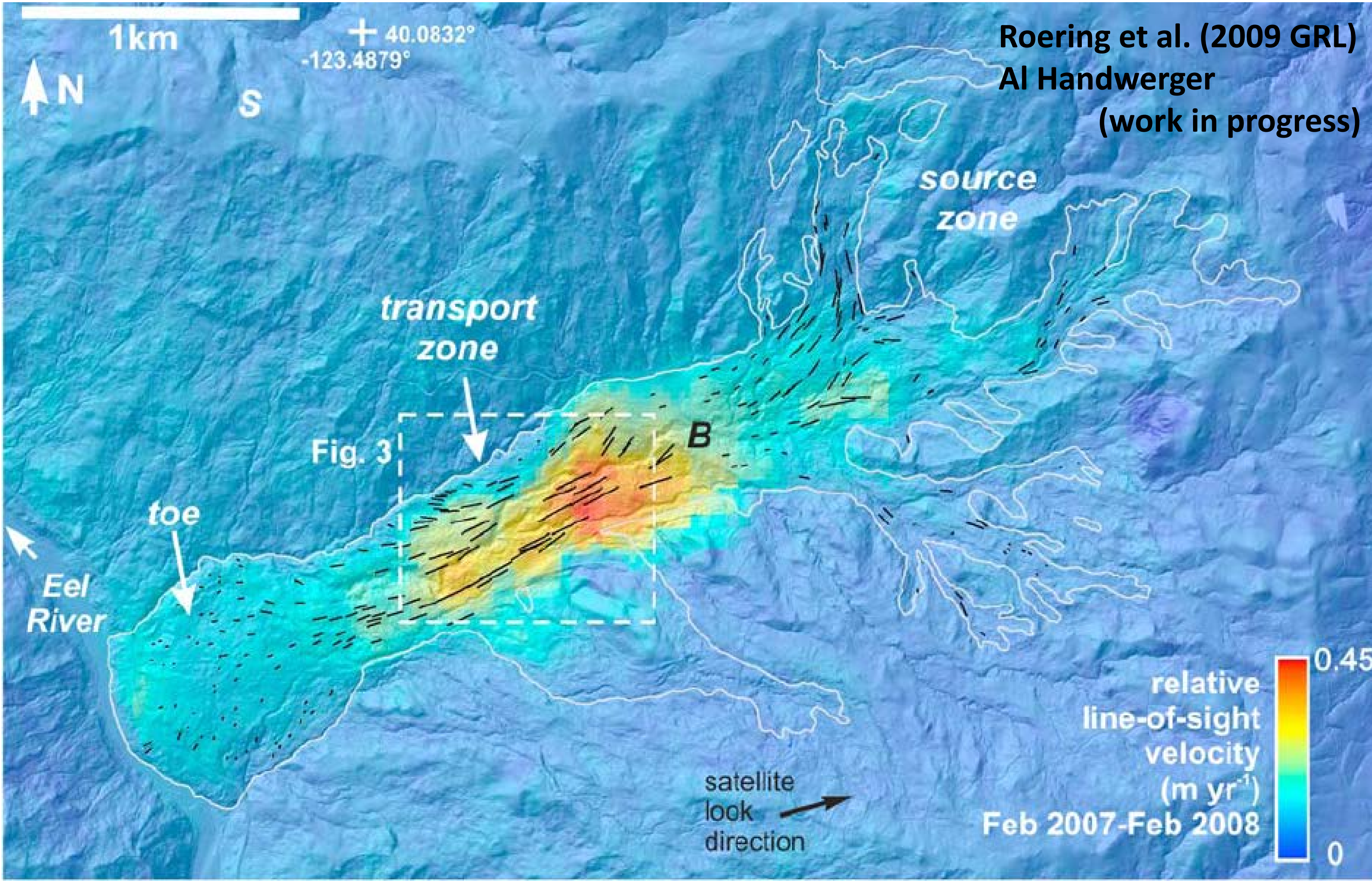
1998-2009

Seam between photos

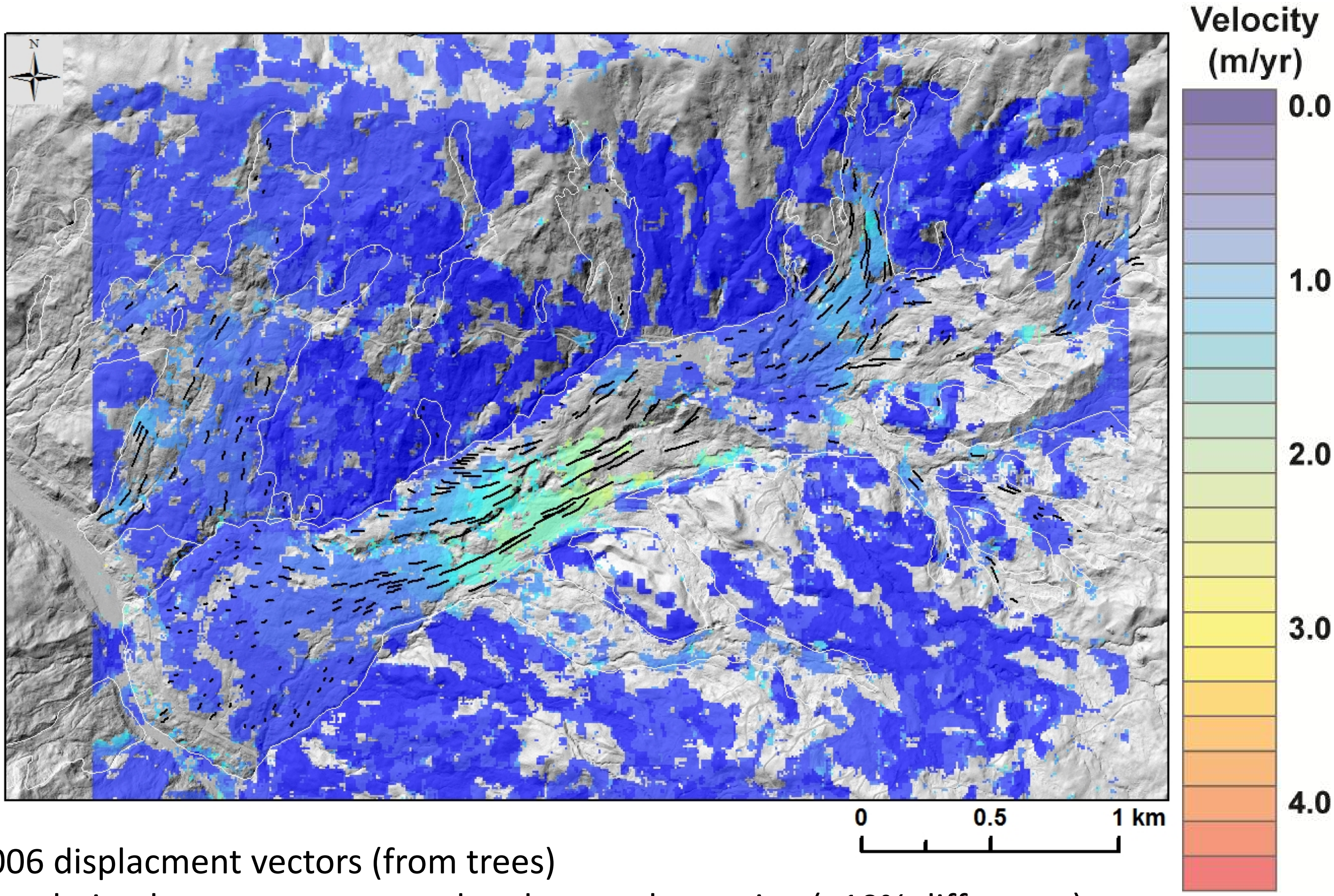


2009 USDA quarter quad - pre-orthorectified
(Rectification error similar to signal)
Flow clearly slowing down (max ~ 1 m/yr)
Northern slide stabilized

Modern InSAR rates ~ 1 m/yr



1944-2009 weighted average



1944-2006 displacment vectors (from trees)
Good correlation between automated and manual mapping (<10% difference)

Summary: Automated mapping of slow-moving landslides

Advantages

- Spatially extensive landslide kinematics over a 65 year period
- Fast, efficient, displacement mapping over large areas
- Don’t need same feature (e.g., a tree) to persist over whole study interval – correlates texture

Issues

- Needs prominent texture for correlation
- Too much change decorrelates (e.g. catastrophic landslides, vegetation change)
    - Although this can still be useful…
- Affected by parallax and sun angle